CHEMICAL & ENGINEERING NEWS

C&EN

JUNE 15, 1992

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FOOD ADDITIVES

THE CHALLENGE OF LOWER CALORIES AND LOWER FATS

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CHEMICAL & ENGINEERING NEWS

C&EN

JUNE 15, 1992

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COVER: Photo courtesy of FMC

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Chemical & Engineering News
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Published by
AMERICAN CHEMICAL SOCIETY
(202) 872-4600; TDD (202) 872-4432
John Kistler Crum, Executive Director
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PUBLISHING BOARD: Ned D. Heindel *(Chairman); Board of Directors Chairman:* Joseph A. Dixon; *President:* Ernest L. Eliel; Richard L. Deming; Judith C. Giordan; William P. Jencks; and Gary J. Long

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Subscription Rates 1992: Printed editions: nonmembers U.S. 1 yr. $105, 2 yr. $189; outside U.S. 1 yr. $141, 2 yr. $261. Air freight rates available on request. Rates above do not apply to nonmember subscribers in Japan, who must enter subscription orders with Maruzen Co. Ltd., 3–10 Nihonbashi 2-chome, Chuo-ku, Tokyo 103, Japan. Tel: (03) 272-7211. Single copies: Current $15. Rates for back issues and volumes are available from Microforms & Back Issues Office, ACS, 1155—16th St., N.W., Washington, D.C. 20036. Back and current issues available on microfilm and microfiche. Rates on request from Microform Program, ACS.

Chemical & Engineering News (ISSN 0009-2347) is published weekly except for the last week in December by the American Chemical Society at 1155—16th St., N.W., Washington, D.C. 20036. Second-class postage paid at Washington, D.C., and additional mailing offices. POSTMASTER: Send address changes to Chemical & Engineering News, Membership & Subscription Services, P.O. Box 3337, Columbus, Ohio 43210. ACS assumes no responsibility for the statements and opinions advanced by the contributors to its publications.

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LETTERS

Environmental science course

I am pleased to read that Princeton University faculty is developing a new course in environmental sciences for nonscience majors with emphasis on chemical principles (C&EN, May 18, page 24).

I authored an outline for a similar course ["Introduction to Environmental Sciences: a Course for Nonscience Majors," *J. Environ. Sci.*, **15**(4), 27 (1982)]. The concept didn't become popular at that time, perhaps because no Ivy League campus was involved or no National Science Foundation megabucks were spent. Nevertheless, it gives me great satisfaction to see some progress in this direction. A vast majority of college students need to learn basic chemical concepts related to environmental issues for their personal and societal improvement.

Gian Gupta
University of Maryland, Eastern Shore

Global warming

You state on the Editor's Page (C&EN, April 27, page 3), "Despite the complexities and uncertainties [of global warming], there are three essentially undisputed facts. . . . The bulk of this 27% carbon dioxide increase has been due to human activity, mainly the burning of fossil fuels."

I would like to inform you that I, for one, cannot accept this statement as undisputed fact. According to my calculations—for which I use internationally recognized, country-by-country consumption data reported for natural gas, coal, and oil in 1988—global fossil fuel consumption is responsible for only up to about 3% of total annual carbon dioxide emissions. The bulk of carbon dioxide emissions is from respiration by biomass and soils and oceanic emissions. The decrease in carbon dioxide sink capacity through such mechanisms as deforestation also plays an important role in carbon dioxide buildup. So unless there is a very efficient separation scheme in operation that selectively removes non-fossil-derived carbon dioxide emissions from the atmosphere, your statement should not be called an undisputed fact.

Based on current technology, the most practical way to reduce ambient carbon dioxide is to grow more biomass, since it fixes considerably more carbon via photosynthesis than it respires. And consumption of biofuels derived from biomass also adds no new carbon dioxide to the environment because of the relatively short recycling time of biomass carbon. Reduction of fossil fuel consumption, especially coal and oil, by increased use of biofuels can reduce atmospheric sulfur oxides, nitrogen oxides, ozone, and unburned reactive hydrocarbons, all of which contribute to subquality air. But elimination of, or a major reduction in, fossil fuel use might be expected to have a small impact on atmospheric carbon dioxide buildup.

Donald L. Klass
President, Biomass Energy Research Association, Washington, D.C.

Computers in chemistry

Can drugs be designed by computers that characterize all molecules as though they existed as gases in a vacuum? When a process as fundamental as absorption of one dioxygen molecule by hemoglobin involves 80 water molecules [*Science*, **256**, 618; 655 (1992)], what can we learn about docking a drug in vacuo? Though the free energy change per water molecule fixed may be small, the involvement of a lot of them can significantly alter geometry and the point of equilibrium.

Not only is there a lot of enthalpy involved in any hydration process, there is also a major entropic change owing to the ordering of what were randomly distributed small molecules. When that large entropy change is manifest in the transition state, it implies existence of a large enthalpy of activation, which, in turn, causes rate to be unusually sensitive to changes in temperature. A similar argument explains why bioequilibria are so often unusually temperature sensitive.

Add to these complications the fact that solvation not only influences targeting a disease area but also affects routes to side effects, and we appreciate that the computer is not about to replace the skilled chemist. (True, a Cray or equivalent supercomputer can surround a molecule with water—given enough time.)

Perhaps all this explains why in six pages on uses of computers in chemistry (C&EN, May 11, page 40) I didn't find mention of any actual contribution to the solution of a commercially significant problem.

Benjamin J. Luberoff
Summit, N.J.

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Market for Polypropylene Is Strengthening as Economy Improves

■ ***U.S. producers raise prices, consider capacity increases, but may face future cuts in exports as foreign capacity grows***

Susan J. Ainsworth, C&EN Houston

After weathering the storms created by the Persian Gulf War and the persistent recession, business is looking a bit brighter for U.S. producers of polypropylene. Demand for the product is strengthening as the economy begins a recovery. In addition, exports, which reached record levels last year, remain strong.

In response, sanguine producers have taken another stab, after the recent unsuccessful attempt late last year, at a polypropylene price increase, hopeful that it will stick. They have also started to think about building the next wave of capacity. Just last month, Phillips Petroleum teamed up with Sumika Polymers America, a subsidiary of Japan's Sumitomo Chemical, to study whether the two will jointly build a 270 million-lb-per-year polypropylene plant at Phillips' chemical complex at Pasadena, Tex., near Houston (C&EN, June 1, page 6).

But some consultants are cautioning that a cloud may soon loom over the U.S. polypropylene market. Capacity is going up all over the world, especially in Latin America and the Far East, and these historical polypropylene importing countries are poised to become exporters. As a result, U.S. exports may sag as these new plants come on stream over the next year or two. That could spark an eventual reversal of any polypropylene price increase producers may get now.

Nevertheless, "virtually every domestic producer is pushing for a 3-cent-per-lb price increase now," says Mark House, vice president for polymers at Houston-based consultants DeWitt & Co. Producers were roughly evenly split on when their increases were to become effective—half had set a June 1 date and the other half had set May 15. Current pricing for injection-grade homopolymer polypropylene is 31 to 33 cents per lb for buyers protected until July 1.

It's too early to tell whether this latest attempt at a polypropylene price increase will be successful. "The vast majority of volume users get 30-day protection, so we won't know how the increase will stick until sometime late in June or into July," House points out. Seven to 10 days after the implementation dates for the new prices, the large-volume users always shop around for deals. The kind of deals they get will depend on how badly some producers want higher prices; some may settle for the additional market share they might get by giving a lowball price, House says.

Still, House gives the increase a reasonable chance of success. He points out that polypropylene operating rates in the U.S. were a healthy 91% in March of this year, based on the latest statistics released by the Society of the Plastics Industry. If those rates hold, he reasons, producers will have more options available and will be more likely to put business at risk to implement an increase. "Demand has been strong and I don't see why it won't continue to be as strong as it has been," House says.

Indeed, demand for polypropylene looks to be healthy now and into the future. Chemical consulting firm Chem System's May 1992 report on polypropylene shows U.S. demand for this polymer will grow from 6.39 billion lb in

Polypropylene demand to be strong through 2000

Billions of lb	1990	2000	% annual growth rate
U.S.	6.39	11.5	5.8%
Western Europe	8.16	17.0	7.6
Japan	4.0	6.0	4.0

Source: Chem Systems

Phillips 66 plant in Pasadena, Tex., has capacity of 480 million lb of both homopolymer and random copolymer resin grades for injection molding, sheet, other markets

1990 to 11.5 billion lb in 2000, posting an annual growth rate of 5.8%. It predicts polypropylene demand in Western Europe will grow even faster, at 7.6% annually. In Japan, the annual growth rate for polypropylene is likely to be 4.0%.

"Demand is up sharply, and we expect that trend to continue as the economy continues to strengthen," says Kenneth F. Dowd, vice president for sales and marketing at Himont, which announced price increases of 3 cents per lb on some of its polypropylene grades, effective June 1. DeWitt's House points out, "There's been a hiccup in housing starts, retail purchases are up, sales of consumer durables have risen, and the packaging market is extremely strong." The only segment that is still lagging significantly is the automotive market, House adds, and only companies heavily into automotive-grade polypropylene are suffering from weak sales and low operating rates now.

Another reason consumption is rising is that buyers are restocking to keep up with the current level of business after starting the year with "lower, cautious inventories," says House.

In addition, the export market continues to soak up excess capacity, thus polypropylene plants can keep running at high capacity. In fact, the U.S. polypropylene market reached a record export level of 2 billion lb in 1991, says House. Polypropylene is still being exported at about 75% of last year's rate, he adds.

Although exports are eating up excess U.S. production and boosting overall polypropylene sales, there's a down side to the boom in exports. Exported product margins are substantially lower than domestic margins, notes Michael Horvath Jr., a petrochemical consultant with Petrocon Associates in Houston. That's especially true for product going into such markets as China and Taiwan, he says. "These markets simply won't pay what the U.S. market is paying for polypropylene homopolymer and some of the higher performance grades. Exports are selling for 5 or more cents per lb less." Despite the high level of exports, companies are not going to see a proportionate jump in polypropylene profits.

Still, the strong demand and export situation is good news for producers, especially Amoco Chemical and Formosa Plastics—two companies that plan to start up additional polypropylene capacity in Texas before the end of this year.

An Amoco spokesman says the company plans to complete its new polypropylene unit at Chocolate Bayou, Tex., "sometime this summer." The unit, based on Amoco's proprietary gas-phase process and high-yield catalyst, will add 300 million-lb-per-year capacity and position the company as a contender in international licensing.

Meanwhile, Formosa Plastics is expected to bring on a 165 million-lb-per-year line of polypropylene at its Point Comfort, Tex., site, by year's end and add two more lines of equal size sometime in early 1993, for a total annual capacity of 495 million lb.

These U.S. expansions are minimal compared with what is going on in other parts of the world, particularly the Far East and Latin America. "The Koreans built a slew of capacity and have flooded the Far East with polypropylene," notes House. In addition, between 1992 and 1993, 15 new plants will go up in that region, adding a total capacity of 2.88 billion lb per year.

Expansions are taking place elsewhere, too. Most recently, Himont and a leading Mexican industrial corporation, Grupo Industrial Alfa, jointly inaugurated their $128 million polypropylene production facility at Altamira, Tamaulipas, Mexico, which will have the capacity to produce 330 million lb per year of polypropylene.

"There are low market entry barriers into the polypropylene business [because] technology licensers are abundant and it is not a high-cost technology relative to other petrochemicals in the production chain," says Don F. Bari, manager of polymer technology at Chem Systems and an author of the firm's polypropylene study. "However, long-term success is very dependent on several factors such as technology selection, market focus, feedstock position, global participation, and R&D effort."

All this new global capacity is becoming a storm cloud that threatens to rain on U.S producers' polypropylene export parade. The Far East and Latin America are now building plants and becoming exporters, Bari adds. Because of this global capacity buildup, exports from the U.S. are expected to decrease significantly.

Although many seem to agree that U.S. polypropylene exports will drop, no one is quite sure when it will happen. Certainly, it will depend in part on the health of the Far East economies. "We originally thought exports would drop off early this year, but now we think that may not happen until the end of 1992 or the beginning of 1993," because of some delays in Far East polypropylene plant startups, Bari says.

Spate of firms compete for polypropylene market in U.S.

	Annual capacity (millions of lb)
Amoco Chemical	
Alvin, Tex.	1,120[a]
Cedar Bayou, Tex.	550
Aristech Chemical	
Kenova, W.Va.	330
La Porte, Tex.	390
Eastman Chemical	
Longview, Tex.	540
Epsilon Products	
Marcus Hook, Pa.	260
Exxon Chemical	
Baytown, Tex.	1070
Fina Oil & Chemical	
La Porte, Tex.	900
Formosa Plastics	
Point Comfort, Tex.	165[b]
Genesis Polymers	
Marysville, Mich.	140
Himont	
Bayport, Tex.	1,050
Lake Charles, La.	1,075[c]
Huntsman Polypropylene	
Woodbury, N.J.	360
Lyondell Petrochemical	
Bayport, Tex.	300
Phillips 66	
Pasadena, Tex.	480
Quantum Chemical	
Morris, Ill.	300
Rexene Products	
Odessa, Tex.	180
Shell Chemical	
Norco, La.	340
Seadrift, Tex.	200[d]
Solvay Polymers	
Deer Park, Tex.	450
TOTAL	**10,200**

a Three hundred million lb of this capacity expected on stream sometime this summer. b Expected to be on stream by the end of 1992. c A portion of this capacity is a joint venture between Himont and China's Impel. d Plant is a joint venture between Shell and Union Carbide Chemicals and Plastics Co. **Source:** SRI International Directory of Chemical Producers, company data

Phillips 66 worker examines test strips of various grades of polypropylene

Under this scenario, the Chem Systems study forecasts that operating rates at U.S. polypropylene plants will decrease to about 80% until at least 1994. In addition, if producers do get all or part of the 3-cent-per-lb polypropylene price increase now, "we may see a reversal of this price trend when new capacity comes on," says Bari.

At least one other consultant believes the new capacity in the Far East and Latin America may not affect the U.S. market as quickly as some fear. Although many countries are building polypropylene capacity to supply demand in their own backyards, the U.S. will still be in a favorable position to supply those markets, says Horvath.

The U.S. has an advantage over many of these nations because of lower costs and better availability of propylene feedstocks. In contrast, many of the new producers outside the U.S. must rely on costly imported feedstocks. As world crude oil prices rise, these countries, especially those that have mostly naphtha-based producers, become less competitive. So even though alternative propylene values may rise in the U.S. (propylene is used to make alkylate for gasoline), the abundance of U.S. propylene will still keep propylene prices relatively low so U.S. polypropylene producers maintain an edge, Horvath says.

"As long as the 'gas bubble' in the U.S. keeps natural gas and natural gas liquids prices low, the U.S. will enjoy a structural advantage over producers in many countries." This factor, he explains, is big enough to offset the cost of transporting resin from the U.S. even though U.S. producers must settle for lower polypropylene prices.

These local producers that must import naphtha feedstock at current market prices and crack it to make propylene will still have significant market share, says Horvath. Despite being higher-cost producers, they will supply their basic local market. Lower cost imports, as from the U.S., will supply the remainder of the market and will likely supply any short-term growth in that market.

Horvath agrees that production outside the U.S. will erode the U.S. export market, but believes it will happen further down the road, beyond 1994. It will depend, he adds, on when the gas bubble disappears, on the growth of U.S. imports of natural gas liquids for ethylene feedstocks, and on the impact of possible foreign government subsidies or import duties that may improve the cost position of local plants.

Even as the U.S. polypropylene industry frets over capacity expansions outside the U.S., producers continue to look ahead to determine when robust demand for their product might outstrip even this new wave of supply. "If you project the growth rate out, we will run out of polypropylene capacity in the 1995–97 time frame," House forecasts. So far, the Phillips-Sumika venture is the only one to announce it is studying whether to build new U.S. capacity to meet demand in 1995. House expects that the venture will not be alone in adding capacity during 1995–97. "We will see a rash of producers planning to build polypropylene capacity. A number of them are studying the situation now."

Because polypropylene demand is growing faster than any of the thermoplastics', House expects to see an expansion in polypropylene ahead of expansions for other plastics. "There's got to be more capacity out there eventually. And the last thing a cagey producer wants to do is be the last to add capacity." □

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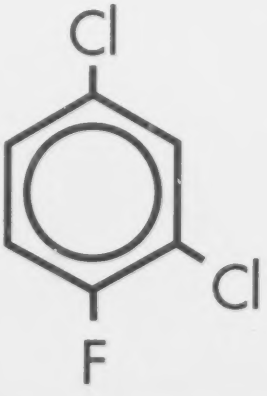

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FOOD ADDITIVES

Ann M. Thayer,
C&EN Northeast News Bureau

Concern over health and nutrition is increasing the public's appetite for low-fat and low-calorie foods. But rather than altering their diets to include foods naturally low in fats or sugar, many people want to continue enjoying the same foods they have always eaten.

According to a survey from the Calorie Control Council, an Atlanta-based trade association, about 75% of the U.S. adult population consumes low-calorie or low-fat foods, and two thirds of those surveyed would like to see the number of available products increase. Such consumer demand is driving food producers to offer new fat replacers and high-intensity sweeteners for entirely reformulated reduced-fat and low-calorie versions of foods.

These influences have made calorie reduction agents the single largest segment of the $3.8 billion market for food additives—accounting for 30% of the total, or $1.17 billion in 1991. This segment is expected to remain the largest through 1996, according to a Pathfinder report from Technomic Publishing Co.'s Business Research Group, Lancaster, Pa. However, the estimated annual 2.1% growth rate belies the activity this market will undergo. In fact, fat substitutes and nonnutritive sweeteners are among the most dynamic of food additive markets.

The calorie reduction industry has been dominated by the billion-dollar artificial sweeteners market, which will drop in value as competition increases. However, the still-new market for fat replacers is expected to grow rapidly over the next several years, and competition will heat up as more and more companies develop products. Obviously, companies would like to be positioned with the ideal combination of a successful sweetener and a successful fat replacer, says J. Charles Forman, an analyst for the Pathfinder report.

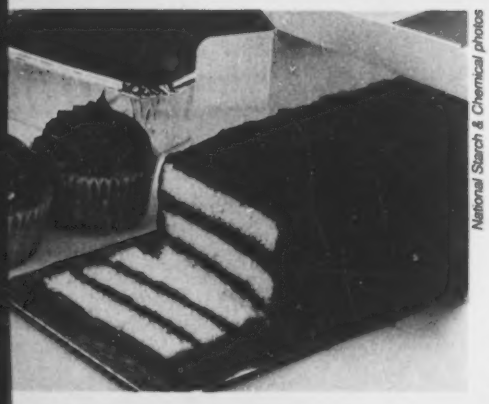
All major food categories and markets offer possibilities for the developers of low-calorie and low-fat food additives, but predicting the direction of these markets is very difficult. Many products face costly, lengthy, and uncertain regulatory approval processes. The Calorie Control Council, for instance, says half of the food additive petitions now being considered for approval by the Food & Drug Administration apply to low-calorie and "light" products. If approved, not only would the number of available products expand, but so, too, would the food categories in which they may be used. For fat replacers, technical hurdles stand in the way of developing effective products and, ultimately, products whose use in new food formulations consumers will accept.

Fat replacers growing market

Fat reduction has captured the interest of the public, and therefore the attention of the food processing industry. Several companies are investing in development of fat replacers, and many already have responded with new products. Although fat replacers had a market value of only about $100 million in 1991, according to the Pathfinder report, it is expected to grow 25% per year and thus triple by 1996. The estimated market for reduced-fat food products is already nearly $30 billion.

Estimates by companies indicate individual products are expected to have annual sales between $50 million and $100 million. This is especially attractive because many fat replacers currently on the market are older materials—starches, gums, and celluloses traditionally used as thickeners and emulsifiers—"dressed up in new clothes" for the fat replacement market. Newer materials are protein-based fat replacers and synthetic or alternative fats.

"There is room for a number of these



National Starch & Chemical photos

products because there are so many different kinds of foods and food formulations," says Forman. Many fat replacers now are used in cheeses, frozen desserts, salad dressings, and mayonnaise-type products. "I question whether there is going to be room for a number of them to really score and become 'megaproducts,'" he adds. Despite consumer surveys indicating a desire for low-fat foods, taste, price, variety, and ease of preparation rank higher than nutritional value among consumer responses.

Lyn Nabors, associate director of the Calorie Control Council, says: "The catch is that people want these products to taste like the regular products. You can get consumers to buy a product once, but if it doesn't taste good, they are not going to buy it again." Many in the industry suggest that there has been a rush to the market with poor-tasting products that can hurt the long-term potential for fat replacers. However, Nabors believes the industry has made strides in the past year or so. "There are more ingredients available and the companies making these low-fat ingredients are providing their customers with some technical expertise by telling them how to use them."

The competitive future of such products will depend on how easy they are for food processors to use, how successfully they behave like fat, and whether products can be reformulated to have the same taste and texture as full-fat versions so as to meet public acceptance. The idea of a miracle ingredient with sales of $500 million or more is not realistic, says Karen Penichter, food market development manager at Chicago-based FMC. "To think that one substance will do everything is a real stretch of technology." There are many different types of fat from a variety of sources, she explains, and each functions differently in a wide range of applications.

"To replace all the attributes of fat is very complicated," Penichter says. Fat has physical properties such as texture, lubricity, viscosity, and structural stability that contribute to its role in foods, as well as its appearance, flavor, and reactivity. "There has been a first wave of reduced-fat and low-fat products, and we have [captured] some of the basics, but consumers and food processors are saying, 'Give me more, give me better.'"

Carbohydrates replace fats

Carbohydrates have provided many early entries into the fat replacer market. Unlike fats with 9 calories per g, carbohydrates such as starches or dextrins (low molecular weight polysaccharides from the partial hydrolysis of starch) contribute 4 cal per g when metabolized. Cellulose, a polysaccharide differing from starch in the configuration of its glycoside linkages, contributes no calories when used as a fat replacer because it is not metabolized by the body.

Starches (a mixture of amylose and amylopectin) can mimic the bulk and texture of fat when mixed with water to form bland gels. The level of starch in fat replacement formulations typically is up to about 25 to 30% of the formulation, depending on the desired gel consistency. Depending on the level of solids, carbohydrate-water mixtures can have properties ranging from oil-like to lardlike. Because water is a major component of this mixture, the number of calories is reduced to 1 cal per g or less. Such mixtures often can replace up to 100% of the fat in many foods, but cannot be used for frying—a major source of fat in people's diets.

Carbohydrate-based fat replacers generally are sold as powders, which have much longer shelf lives and avoid the added costs of shipping premixed gels. Food processors must mix the powders with water, either before or after mixing with other ingredients.

When heated, stirred, and cooled, these fat replacers form a fatlike material. Because modified food starches have long been recognized as safe to consume, many starch-based fat replacers have shown up on FDA's GRAS list (generally recognized as safe) and have entered markets easily.

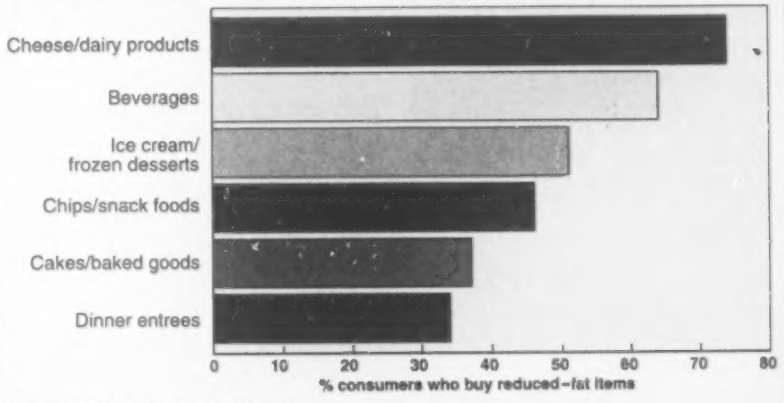
In January, National Starch & Chemical launched a line of fat replacers called N-Lite, designed to replace fats in a variety of foods applications. Doubting the utility of a "magic bullet" approach, the company worked with corn and other starches to develop what it calls a "systems approach" to fat replacement. This approach differentiates its products from those of other firms, says the company, because it recognizes the properties and roles of different fats in foods and then tailors the starch to have the organoleptic and functional properties needed for specific applications.

"The challenge is to make starch, a hydrophilic polymer, behave as fat, a hydrophobic monomer," says Peter Trzasko, a research associate at National Starch. Fat is not a single compound, but rather a family of triacylglycerols, which consist of three fatty acids, saturated or unsaturated chains generally composed of between eight and 18 carbons, esterified to a glycerol backbone. Depending on the combination of chain lengths and the degree of unsaturation, fats will have very different physical properties, and, therefore, different uses.

The associations between starch molecules can be controlled to mimic fat's properties, explains Trzasko, depending on the starch's chemical structure and how it is physically processed. Conventional methods of starch modification result in the random generation of molecules with wide distributions of sizes and shapes. By selecting the source of the starch and using proprietary, novel enzymatic or chemical hydrolytic procedures, National Starch controls the modification process.

N-Lite B, for example, is a specialty maltodextrin for use in baked goods. Reduced-fat baked goods, considered by many to be a major challenge, must retain moisture and a doughlike or cakelike structure. For frostings and fillings, N-Lite F, a mixture of modified food starch, nonfat dry milk, emulsifiers, and guar gum is used. The starch and gum give the mixture the body and feel of fat, whereas the dry milk acts as a stabilizer, and a polyglycerol ester emulsifier traps air during whipping.

Low-fat dairy products are most popular reduced-fat foods



Source: Calorie Control Council 1991 survey

N-Lite D is a modified food starch for use in dairy foods. Formulated for liquids for uses other than frying, N-Lite L and N-Lite LP are oily, viscosity stable, and stable to any heat and shear that might occur in food processing. N-Lite L is designed for systems requiring cooking, such as sauces and puddings, where high enough temperatures are reached to cause its modified starch to gel. N-Lite LP is pregelled for instant-food applications.

National Starch also has developed two products derived from tapioca. N-Oil is a maltodextrin for salad dressings and dairy-type products. Slenderlean, a modified starch, can be used at levels of only 1% by weight to reduce the fat in sausages to less than 10% by weight.

Other starch-based or maltodextrin-based fat replacers are sold by Grain Processing Corp., American Maize Products, Remy, Avebe, and A. E. Staley. Staley, the Decatur, Ill., affiliate of England's Tate & Lyle, produces Sta-Slim, made from modified potato and tapioca starches. Grain Processing Corp., of Muscatine, Iowa, produces a cornstarch maltodextrin product called Maltrin, and Dutch company Avebe makes Paselli-SA2, a potato starch maltodextrin.

Rhône-Poulenc's U.S. arm in Cranbury, N.J., has teamed up with Quaker Oats to develop and market Oatrim. Licensed from the Department of Agriculture to the two companies and to ConAgra of Omaha, Oatrim is produced by the enzymatic treatment of oat flour and oat bran. Its high β-glucan content, says Richard V. Kennedy, senior vice president and general manager of Rhône-Poulenc's food ingredients unit, gives a creamier taste and texture than other fat replacers. Rhône-Poulenc will have marketing and sales responsibilities for Oatrim food ingredient products made from materials supplied by Quaker Oats.

A year ago, Staley introduced Stellar, an acid-modified cornstarch, as a fat replacer for a variety of food applications. Unlike cellulose particles and some starches that undergo syneresis—losing water and thickening over time—Stellar retains water and its fatlike qualities, making it useful in low-moisture reduced-fat foods, says Sylvia Wulf, marketing manager for new products at Staley. Moderate heat processing is possible, up to about 70 °C, but Stellar can't undergo the retort or aseptic processing used in canned foods. Its stability to heating, freezing, and thawing also depends on the presence of other ingredients. By lowering the pH and adding a preservative to avoid microbial growth, the material can be stored for a few weeks under refrigeration.

Stellar is made by a process that modifies largely insoluble starch granules by depolymerizing the amorphous amylopectin portion to yield fragments with an average molecular weight about one tenth that of potato maltodextrin or tapioca dextrin. Under high shear or pressure (8000 psi or more), the particles adsorb water and immedi-

CIRCLE 2 ON READER SERVICE CARD →

ately form a particle gel (versus a typical starch polymer gel) that is similar to shortening. The gel consists of 2.5- to 15-μm aggregates of submicrometer starch particles, explains Wulf, and it is these soft, deformable particles that make Stellar behave as fat globules. The company provides samples of the gel or "crème" for evaluation and technical support services for the shearing process.

Stellar is more expensive than other starches, says Wulf, but less expensive than microcrystalline cellulose and much less expensive than NutraSweet's protein-based fat replacer, Simplesse. Most companies are reluctant to give figures for the price of their products, but industry estimates place Stellar at about $2.50 per lb. However, a more important competitive measure for fat replacers will be their cost versus use levels. According to the Pathfinder report, the cheaper carbohydrate-based products, if they work as well as claimed, will take over the fat replacer market. But it is likely no one product will dominate because the needs are very different in different foods.

Carbohydrate gums and hydrocolloids have been used for many years as thickeners, stabilizers, or emulsifiers in foods. Common hydrocolloids that are fermentation products, or seeds, plant exudates, and plant extracts—xanthan gum, guar gum, locust bean gum, gum arabic, pectin, and carrageenan—are very effective in their ability to "structure" water. As fat replacers, they can be used in very small amounts and essentially are noncaloric. Gums and hydrocolloids average a few dollars per pound, depending on how exotic their source.

Hydrocolloids may be used alone or in combination with other gums or fat substitutes to replace fat. When fat is removed from a product and replaced with a mimetic and water, a hydrocolloid is frequently added to develop texture, viscosity, or stability.

Among suppliers of these substances, Rhône-Poulenc has sold gum and hydrocolloids to the food industry for more than 40 years and has been expanding its business through acquisitions. Dow Chemical is a major producer of methylcellulose food gums, part of a major class of synthetic gums. Hercules produces carrageenan, extracted from seaweed, and a variety of gums, especially pectins. Pectins have been used for years in the food industry to thicken or gel aqueous systems such as jams or jellies.

In late 1991, Hercules introduced its Slendid product as a fat replacer. Slendid is a specialty pectin, or partial methyl ester of polygalacturonic acid, extracted from citrus peel. To use Slendid as a fat replacer, it is mixed at a level of 5% or less with water and a source of calcium to make it gel. As the gel forms, it is exposed to moderate shear to break it up, explains Noo Mangat, director of new business development for Hercules' food ingredients group. The resulting material has the consistency of applesauce and can be used "as is" in food formulations. If Slendid is to be used in a smooth formulation, such as a salad dressing, it can be homogenized to become creamy.

The size of fat particles depends upon how they are processed, says Mangat, and by no means fall in a narrow size range. Slendid's advantage over other products is that it behaves as a fat, he adds, breaking up or mixing under normal processing. Its small, stable pieces of gel simulate the behavior of an emulsified fat and, being soft and deformable, give the gel a fatlike feel. Other features include a fatlike meltability and a heat stability that allows for sterilization or pasteurization cycles such as those used for canned cream soups.

In practice, even replacing up to 100% fat with Slendid, it would appear at a level of only about 1% by weight of the food product and contribute negligible calories. On a cost versus usage level, says the company, it rivals other fat replacers. A principal advantage of pectin, adds Mangat, is that it is an extremely consumer-friendly food additive, as is starch. Thus, he believes changes in FDA labeling regulations, which may cause consumers to look more closely at food labels, will be positive for Slendid. Although meeting GRAS standards, USDA has not approved Slendid's use in meat products.

Another major producer of hydrocolloids is FMC. Like Pfizer, Rhône-Poulenc, Monsanto, and Hercules with new products in the area of "light" food ingredients, FMC's formation of a new food ingredients division demonstrates its commitment to the fat-replacer market. The company has consolidated marketing, technical, and business operations for its carrageenan, microcrystalline cellulose, and konjac flour materials.

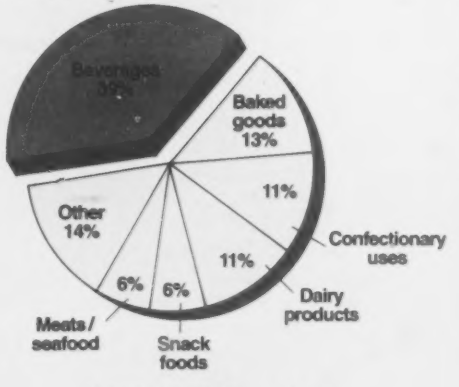
FMC is the world's leading producer of carrageenan, currently used by meat processors to formulate low-fat ground beef products. FMC's Nutricol konjac flour, derived from an Asian tuber, has

Fat replacers to show largest growth

	Sales ($ millions)			% annual growth
	1988	1991	1996	1991–96
Fat replacers	$ 50	$100	$ 305	25.0%
Nonnutritive sweeteners				
Tabletop uses	175	220	316	7.5
Other applications	750	850	675	–4.5
Formulation aids[a]	850	920[b]	1084	3.3
Flavors & enhancers	575	675	911	6.2

a Includes emulsifiers, surfactants, thickeners, stabilizers, binders, and fillers. b Includes hydrocolloid gums at $270 million, cellulose and derivatives at $200 million. **Source:** Technomic Publishing's Pathfinder report

Beverage industry uses most food additives



1991 food additive sales = $3.83 billion

Source: Technomic Publishing's Pathfinder report

CIRCLE 2 ON READER SERVICE CARD

a unique ability to replace fat in meat products, says Penichter. In combination with starch or xanthan gum, it forms a stiff, heat-stable gel that can be handled like meat trimmings and will not degrade during cooking. FMC is awaiting USDA approval for Nutricol's use in meat products.

FMC is now promoting its Avicel microcrystalline cellulose, long used in drug tablets, as a fat replacer in frozen desserts, salad dressings, and bakery products. Avicel, a purified form of natural cellulose, consists of particles about 0.2 μm in diameter that, when mixed with water, form a network with a texture similar to fat. FMC also produces other versions with larger diameters, 10 to 15 μm, or rounded particles, says Penichter. Since cellulose is not metabolized, Avicel acts as a nonnutritive fat replacer.

Pfizer reformulated its polydextrose bulking agent, long used to replace sugar, and began promoting it as a fat replacer called Litesse in early 1991. The company is investing "significant resources to expand its position as one of the world's leading suppliers of 'lite' food ingredient systems," says Donald F. Farley, executive vice president of the Pfizer Specialty Chemicals Group. In late 1990, Pfizer sold its citric acid business as part of its new strategic focus on "performance food ingredients and proprietary, customized food additive systems and applications technologies."

This month, the company announced it will make a second-generation version, Litesse II, available later this summer for customer scaleup and test marketing. The newer version, says the company, is improved measurably

C&EN staff photo

Table-top uses are growing market for nonnutritive sweeteners

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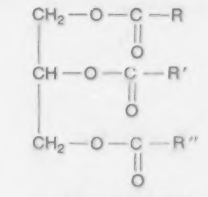
in taste quality so that it may be used in highly flavor-sensitive foods. At 1 cal per g, both Litesse versions can be used as bulking agents or to replace fat in baked goods, frozen desserts, yogurts, sauces, and spreads.

Proteins to form particulates

Protein-based fat replacers are designed to mimic the lubricity of fat through the use of small particles. With diameters of 0.1 to 3.0 µm, protein particles are perceived in the mouth as "creamy." Like carbohydrates, protein has 4 cal per g, and contributes fewer calories in fat replacement systems where the particles are mixed with water. Some protein-based fat replacers can be used in baked applications but, like several other fat replacers, cannot withstand the heat used in frying.

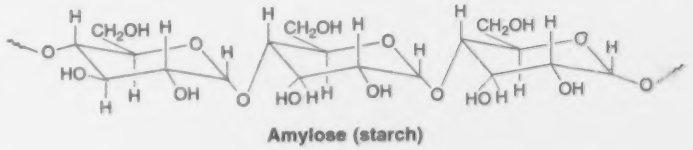
Simplesse, marketed by the Monsanto subsidiary NutraSweet—producer of the aspartame sweetener sold by that name—is the only protein-based fat replacer available in the U.S. Two versions are available, based on different

Polysaccharides' structure differs from fats' structure

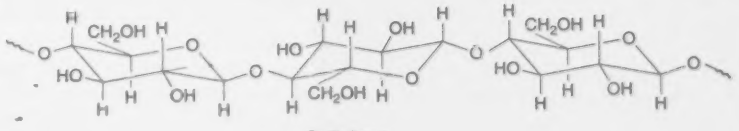


A triacylglycerol (fat)

R, R′, and R″ generally are saturated or unsaturated straight chains containing between eight and 18 carbon atoms



Amylose (starch)



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materials--one is microparticulated egg white and milk proteins, and the other is whey protein. The company's patented process combines high heat—above pasteurization temperatures—and high shear to form the proteins into spherical particles. Simplesse is sold either in a liquid form or as a powder, the latter offering economies of transportation and a significantly longer shelf life.

In early 1990, FDA categorized the egg- and milk-based Simplesse as GRAS for frozen desserts. This was after an aborted attempt to launch the product two years earlier when the company announced that its product did not require approval because it was made from GRAS materials. The lesson learned when FDA intervened, say industry observers, was that "GRAS plus GRAS does not equal GRAS." In 1991, the liquid or dry whey version was permitted for use in cheeses, salad dressings, and mayonnaise products. Applications are pending with FDA for further uses of the egg-milk version.

In 1990, NutraSweet launched Simplesse only in its own frozen dessert product, Simple Pleasures, putting itself in competition with its potential customers. The company is enthusiastic about its dessert products, which it says are in 85% of U.S. markets and are the top "unit" seller, but not necessarily top volume seller, among low-fat/fat-free frozen desserts. Despite this, many industry observers question the wisdom of NutraSweet's approach.

"Some new fat replacer products

Continued on page 36

Fat replacers integral to new food formulas

Fat replacers are being used as major ingredients in many salad dressings, mayonnaise, and dairy-type products. Most fat replacer systems can be combined with other dry ingredients and then mixed with water. Alternatively, they may be prepared first as a gel or crème under the necessary mixing or heating conditions, and then added to the food product. For example, Stellar, an acid-modified cornstarch, requires high shear to make its particles adsorb water and form a shorteninglike gel. Processing Stellar in standard equipment with other ingredients could follow the type of food formula given here.

7.5% Fat Cheese-Flavored Spread	% wt
Stellar fat replacer crème[a,b]	39.30%
Water	29.63
Cheese powder	22.50
Nonfat dry milk	5.82
Mira-thik 468 starch[b]	0.65
Instant Tender-Jel 419 starch[b]	0.52
Lactic acid, 88%	0.34
Flour salt	0.32
Citric acid, powdered	0.26
Dipotassium phosphate	0.20
Color, red #40, 0.01% solution[c]	0.16
Potassium sorbate	0.15
Color, yellow #08031, 5% solution[c]	0.15

a 27% modified food starch and water. b A. E. Staley products. c Warner Jenkinson products. Source: A. E. Staley

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Continued from page 32

have not been the barn burners they were supposed to be," says Forman. "NutraSweet and other firms have learned that low-fat dairy desserts do not have the consumer appeal of ice cream." Simplesse is a primary example, he adds. "[It] has not made the great market splash hoped, is considered a disappointment by many in the food industry, and has been written off by some analysts as a product with high cost and limited advantage." NutraSweet had projected sales of Simplesse products at about $450 million by 1992, he says. Yet Simple Pleasures' sales totaled only $12 million in 1990 and have not grown greatly since.

NutraSweet has gone on to market Simplesse as a food ingredient. It is used in 18 products worldwide appearing in several regional products in the U.S. The Simplesse logo is used on these products because, says a company spokesman, "consumers are a little bit confused by what's out there. . . . By putting the logo on products, it helps consumers because they know it's natural, it means good taste, and above all it means a reduction in fat."

Kraft developed a microparticulated protein-based fat replacer, Trailblazer, for in-company use—but ended up not using it after all. Instead, Kraft markets low-fat or fat-free products in 12 categories—more than any other company, it says. "During the time Kraft applied for GRAS approval [of Trailblazer], the company introduced all these other products using common natural ingredients that have been used for years and didn't require approval," says a company spokesman. "Kraft has been very satisfied with the quality."

Still under development is Lita, based on zein, a microparticulated protein from corn. Pfizer's specialty chemicals group has joined with Opta Food Ingredients of Cambridge, Mass., to develop the product. Like other protein-based fat replacers, it contributes less than 2 cal per g, has a bland taste, and can be produced in a liquid or powder form. The companies are said to be testing Lita in frozen dessert, whipped topping, and mayonnaise applications.

Alternative fats being developed

Several companies are developing synthetic fats or chemically altered fats, but to date none has been or is expected to be approved in the near future. In most cases, by altering the size, shape, or structure of fatlike molecules, the human body metabolizes these materials to a lesser extent, if at all. These are attracting attention both because of their synthetic nature and because they would be the first products to make inroads into frying applications. The best-known example is Olestra from Procter & Gamble.

Olestra is a sucrose polyester containing six to eight fatty acids esterified to sucrose, instead of glycerol. The fatty acids are derived from vegetable oils such as corn or soy. Being larger than a typical fat molecule, it is not hydrolyzed by digestive enzymes, not adsorbed, and passes through the digestive tract unchanged, says Procter &

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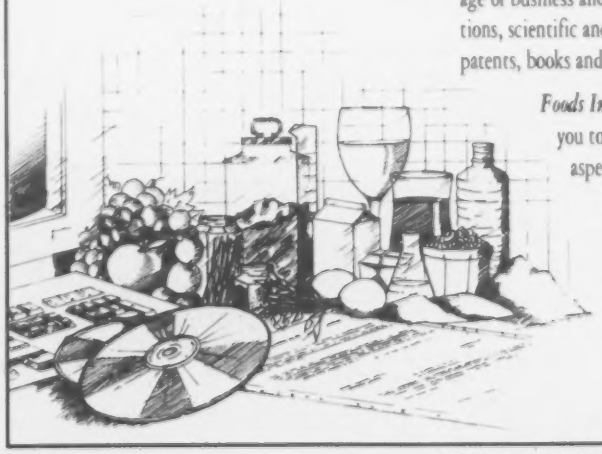

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Gamble. But, being chemically like a fat molecule, it is described as having physical properties, taste, and performance similar to a conventional fat. In practice, it could replace 100% of fat in fried foods and offer a corresponding reduction in calories.

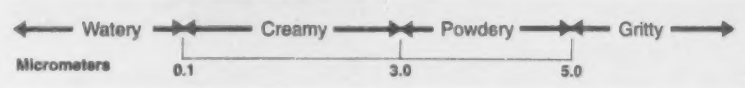
The company has been in discussions with FDA over Olestra since the early 1970s, spending millions of dollars and decades in developing and testing its product to meet safety standards. Since 1987, a 20,000-page petition that includes more than 100 animal studies and more than 25 clinical studies has been submitted to FDA for Olestra's approval as a food additive. In 1990, the company narrowed its petition to snack-food uses. Health issues, such as whether the product causes diarrhea or depletes the body of vitamins, have been raised but successfully answered, says the company.

Olestra's case is illustrative of more general issues. Among these is FDA's well-known caution in approving food additives. This is true especially for new materials with which it is unfamiliar and about which questions of inertness or innocuousness arise. Fat replacers pose questions about the quantity of additives in food because, unlike high-intensity sweeteners used in very small amounts, they might constitute a larger component of people's diets. Not only does the regulatory process become lengthy, say many in the industry, but when FDA does act, it often initially approves a product for very limited uses. Thus, older ingredients with a history of use and demonstrated safety either have not required, or have broader, approvals and have become more usable materials.

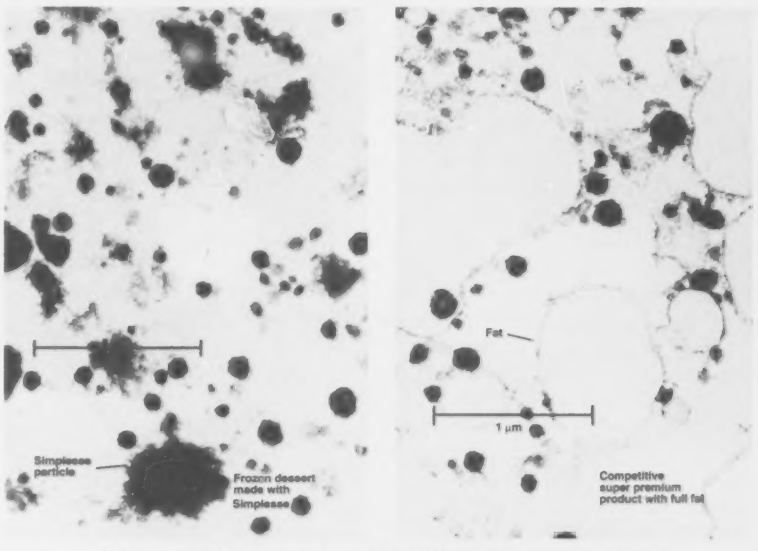
For example, in a 28-g serving of potato chips, Olestra would replace 100%, or 9.8 g, of fat from cooking and reduce the total calories 57%. Because of Olestra's long delay at FDA and because patents expire in 1994, Procter & Gamble has requested a patent extension from Congress. Although NutraSweet was granted an extension on aspartame for similar reasons, this action on Olestra has been widely criticized by several consumer groups. Only recently, Procter & Gamble disbanded its Olestra marketing effort.

Procter & Gamble also has developed caprenin, a reduced-calorie fat, with functional properties similar to cocoa butter. It differs from most fats in

Fatlike feel depends on particle size



Source: NutraSweet Company



Micrometer-size Simplesse particles (left) mimic "creamy" feel of butter fat in ice cream (right)

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National Starch & Chemical photo

Technicians work with new additives in food formulations

that two of its fatty acids are unsaturated medium-chain acids, caprylic (C_8) and capric (C_{10}), and the third is behenic acid (C_{22}). Caprylic and capric acids are obtained from coconut and palm kernel oils, whereas behenic acid is found in peanuts, some marine oils, and hydrogenated rapeseed oil. The combination of behenic acid, which is only partially absorbed by the body, and the medium-chain acids, which are metabolized like carbohydrates, yields a fat with 5 cal per g.

Caprenin is targeted at markets such as soft candies and confectionery coatings for fruits, nuts, and cookies, says the company, because it provides the rich, creamy, and chocolately taste of cocoa butter. Early this year, Procter & Gamble began selling caprenin, which is based on GRAS materials, to Mars for use in candy bars. Procter & Gamble has filed a petition with FDA to affirm caprenin's status as GRAS.

Similarly, Arco Chemical, a subsidiary of Atlantic Richfield, is working on chemically modified fats. Its esterified propoxylated glycerols (EPGs) are naturally occurring fats with propylene glycol inserted between the glycerol and fatty-acid segments, explains Eileene Keating, EPG project manager at the company. "Because they are based on naturally occurring fats and oils, they tend to function as a fat or oil in food applications," she says. "However, because they consist of a larger molecule, the body doesn't recognize them as a fat or oil and essentially they are either not metabolized or metabolized to a far lesser degree [than a fat or oil]."

The properties of the material can be adjusted depending on the fatty-acid structure and the number of propylene glycol units inserted. "We have quite a few degrees of freedom in tailoring the EPG molecule," says Keating. "In today's industry, there currently are a number of fats and oils being used, each tailored to specific applications. No one fat or oil, be it a high-caloric or low-caloric one, is going to serve all needs." The company expects that several years will be needed to complete development, safety testing, and the regulatory approval process before commercialization.

"The products that currently are being used commercially as fat mimetics are based on carbohydrates or proteins," says Keating. "By their very nature, they cannot mimic all the different characteristics that a fat has in a food product." Like Olestra, Arco Chemical's patented EPGs could be used in frying or food formulations for reduced calories. "Olestra and EPG represent two products that have the potential of acting as true fat replacers in the literal sense."

A number of other alternative fat products are under development or are in use. For instance, one under development by Dallas-based Frito-Lay is dialkyl dihexadecylmalonate (DDM), a noncaloric fatty alcohol ester of malonic and alkylmalonic acids. Another one, previously under development by CPC

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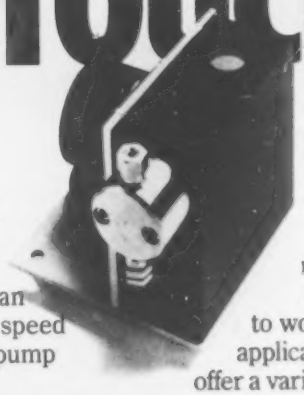

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CIRCLE 28 ON READER SERVICE CARD

International, Englewood Cliffs, N.J., is TATCA, or tricarballylic acid esterified with fatty alcohols, but that project has been put on hold.

Stepan, in Northfield, Ill., sells alternative fats for use in food applications. Its primary product is Neobee M-5, a medium-chain triglyceride (MCT) containing fatty acids obtained from mixed triglycerides in coconut oil.

Although only about 1 cal per g less than a typical fat, MCTs are metabolized more like carbohydrates, explains Joanne Kennedy, technical service representative at Stepan, and are burned for energy rather than stored. A drawback of MCTs is that, when hydrolyzed, the resulting free fatty acids have an "off" flavor that is difficult to mask. At this point, it is also not known whether these, and other alternative fats, will be considered as fats and counted toward total grams of fat and calories from fat on food labels.

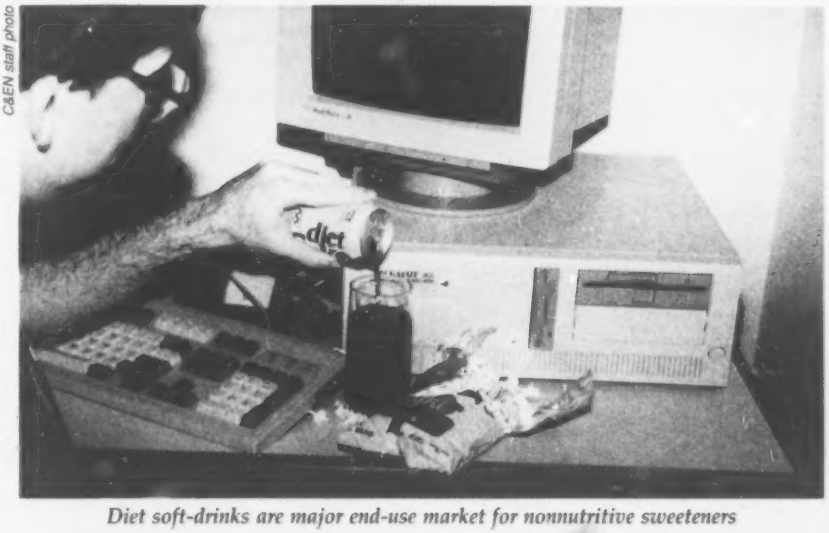
This year, Pfizer began marketing a fat extender called Veri-Lo. Using a proprietary emulsion system in water, the fat-containing product forms gel particles. The particles are about the size of typical fat globules, says the company, and fat-coated so that Veri-Lo is perceived to taste and behave like fat while offering significant calorie reductions. Veri-Lo is a GRAS product intended for low-temperature applications such as mayonnaises, sauces, dressings, and dairy foods.

It is sold in two ready-to-use liquid forms for replacing 67 to 75% of fat. Veri-Lo 100 contains 33% soybean oil with 3.1 cal per g. Veri-Lo 200 contains 25% milk fat and 2.3 cal per g. Pfizer's products are a compromise between the flavor that fat contributes and fat reduction. Others in the industry acknowledge that making products without fat is difficult and that many may have serious flavor defects. Some even suggest that small amounts of fat, qualifying for low-fat rather than fat-free standards, may creep back into foods to compete with better tasting products.

Dynamic sweeteners market

Low-calorie sweeteners are another way of reducing calories in food. The expiration of NutraSweet's aspartame patent in December 1992 and the anticipated regulatory approvals of new high-intensity sweeteners make these one of the most dynamic, yet uncertain,

C&EN staff photo

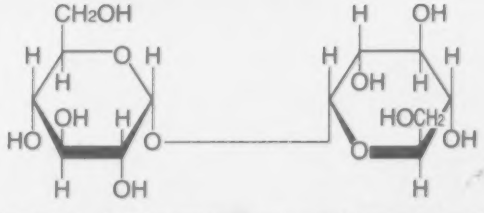


Diet soft-drinks are major end-use market for nonnutritive sweeteners

of food-ingredient markets. Sweeteners are the largest segment of the calorie reduction products market in the U.S. at $1.07 billion in 1991, according to the Pathfinder report. Despite all the anticipated activity in this area, the market is expected to grow only 2.1% a year to $1.3 billion by 1996, primarily because of reduced pricing.

The market is dominated by aspartame (*N*-L-α-aspartyl-L-phenylalanine 1-methyl ester), which was approved

Innovative Applications with Trehalose



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CIRCLE 23 ON READER SERVICE CARD

Labeling laws to change information on food packaging

New food labeling regulations mandated under the Nutrition Labeling & Education Act (NLEA) of 1990 will have a major impact on the information consumers get about the food they eat. Proposed regulations from the Food & Drug Administration were released in late 1991 and will go into effect six months after a public comment period ends in November 1992.

The proposed regulations give guidelines for mandatory nutritional information on all processed foods. FDA repeatedly has expressed the desire to have labeling that is accurate, consistent, and credible while being understandable and useful to consumers. In addition to listing specific ingredients, labels will be required to include descriptive nutritional information, limits on health claims, and standard serving sizes on more than 130 categories of foods to allow for easier nutritional comparisons.

Listed on labels will be such items as total calories, total fat, calories from fat, cholesterol, total and complex carbohydrates, total sugars, dietary fiber, protein, sodium, vitamins A and C, calcium, and iron. FDA evaluated health claims as related to diet and will allow four to be included in labeling: calcium and its role in osteoporosis, sodium and its role in hypertension, and fat and its role in heart disease and its role in cancer. Precise definitions for terms such as "light" or "lite," "low," and "free" also would be established.

The proposed regulations define low fat as less than 3 g per serving and per g, and fat free as less than 0.5 g per rving and per 100 g. Using the label, "X% fat free," would be possible only if a product meets the low-fat criterion, and "reduced fat" would apply to products in which fat has been decreased 50% and at least 3 g. The term light would refer to foods that are one third lower in calories than comparable non-calorie-reduced versions. "Low calorie" would refer to foods with less than 40 cal per serving and per 100 g. "Reduced calorie" foods would be required to be reduced at least one third and by at least 40 cal. When a product contains less than 4 cal per serving, it would be able to be called "calorie free."

Producers of fat replacers are opposed to what they consider overly stringent definitions proposed for light, says the Calorie Control Council in Atlanta. If 50% or more of a food's calories come from fat, there also must be a 50% reduction in fat in addition to a one-third reduction in

by FDA for table use and in dry beverage mixes in 1981. Since then, approvals have expanded its use into a range of product areas. In the U.S., aspartame is marketed by NutraSweet. Although it is metabolized in the human body, it is essentially noncaloric—because it has 180 times the sweetness of sucrose, only very small quantities are used.

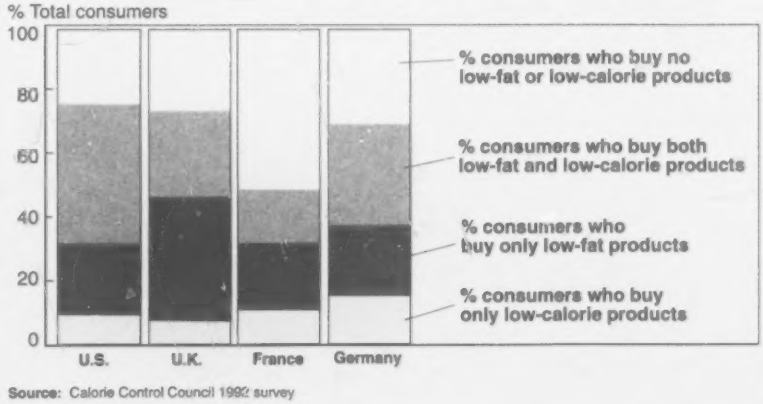
NutraSweet has aggressively marketed its sweetener, with customers displaying a NutraSweet logo on their products. This has contributed to 98% name recognition, says the company, and has helped position the product for the time when the patent expires. To maintain its head start and compete against generic forms to come on the market in the U.S., NutraSweet has been expanding production both here and overseas, and attempting to lower its production costs. Construction of a new French plant began in 1991 as part of a joint venture with Ajinomoto of Japan.

With a monopoly in the U.S., NutraSweet has been able to charge more than $50 per lb for aspartame. But pricing will be a driving factor here as it has been in Europe and Canada, where prices fell to about $30 per lb when patents expired. NutraSweet anticipates its sales to drop $250 million in 1993 because of a falloff in prices, rather than volume. However, Coca-Cola and Pepsi have signed long-term supply agreements with NutraSweet for use of aspartame in their diet soft drinks. With growing competition and estimated 30% price reductions for aspartame, the market for nonnutritive sweeteners in uses other than table use (such as for sweetening coffee or tea) is expected to decrease 4.5% a year, from $850 million in 1991 to $675 million by 1996, says Forman; however, volumes will increase.

In Europe and Canada, NutraSweet has faced competition from Holland Sweetener, a joint venture between DSM of the Netherlands and Tosoh of Japan. Based on a complaint from Holland Sweetener, the European Community imposed an antidumping fine of about $40 per kg on NutraSweet and Ajinomoto in 1991. With about 30% of the European market, Holland Sweetener has made clear its determination to enter the U.S. market, which accounts for about 80% of worldwide sweetener sales, and has been quadrupling production capacity to do so.

Competition is expected from other high-intensity sweeteners, which could get FDA approval in the next five years, although exactly when is uncertain. With more products available, Forman explains, prices might reach a

U.S. has highest consumption of low-fat, low-calorie products



Source: Calorie Control Council 1992 survey

calories to warrant the term light. Reductions of 50% in fat are not feasible for all product categories, adds the council, or in some cases significant reductions are possible, but the food does not meet quantitative thresholds. And, reductions in both fat and calories may not be possible when fat is replaced with carbohydrates or proteins that contribute calories. The council proposes light apply to a one-third reduction in fat, with or without a reduction in calories.

A positive factor for low-fat or low-calorie foods may be a relaxing of the "standards of identity." The standards make it possible to call a food by a given name only if strict compositional definitions, sometimes including high levels of fat, are met. If not met, a product would have to use the terms "imitation" or "artificial." Because these terms lack marketing appeal, food processors had been discouraged from producing potentially healthier low-fat or low-calorie versions. Changes allowing a permitted nutrient descriptor with the name of a food—as in "low-fat ice cream"—are hoped to provide new incentives for food processors.

Reaction from the food industry to the basic FDA principles to move away from misleading labeling, such as those based on minuscule serving sizes, ranges from enthusiasm to resignation. Generally rejected, though, is the brief time given for compliance and completion of what is seen as a massive and costly task, as much as $4 billion according to food industry estimates, of relabeling foods. As part of the response, many companies and organizations have petitioned FDA to extend the time for implementation. The Department of Agriculture, which regulates marketing of meat and poultry products, has said it will set up similar rules, but will delay doing so until May 1994.

Many believe that once the initial task of compliance is over, food producers will be encouraged to develop more nutritional products that warrant desirable nutritional descriptions or claims on a label. At the same time, food processors are calling on FDA to streamline its approval process for new ingredients or additives, such as sweeteners and fat replacers, that might make these foods possible. However, as the number of additives continues to grow, there is little reason to believe FDA will become any less cautious in its approach to approval.

"sugar equivalent" of about $20 to $30 per lb. Further complicating the dynamics of the U.S. market is that FDA approvals often are food-application specific, such that two approved sweeteners may not compete directly in the same product areas.

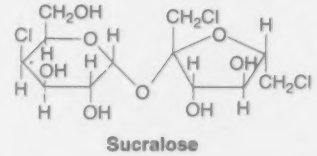
Baked goods are an untapped area targeted by many of the new products. One of aspartame's drawbacks has been its lack of stability under heat and/or acidic conditions. Last month, an encapsulated form of aspartame was approved in Canada for high-temperature applications and a similar application is pending in the U.S.

In 1988, after six years of review, FDA approved acesulfame-K (the potassium salt of 6-methyl-1,2,3-oxathiazin-4(3*H*)-one 2,2 dioxide) for use in dry mixes, table uses, and chewing gum. Unlike aspartame, acesulfame-K is heat stable and has a longer shelf life. Acesulfame-K is marketed by a division of Hoechst Celanese, based in Edison, N.J., under the Sunette tradename. It is used in more than 600 products in more than 35 countries and is awaiting FDA approval for other uses in the U.S. At 200 times the sweetness of sucrose, acesulfame-K is not metabolized and is noncaloric.

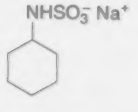
Because of what some view as its structural similarity to saccharin, a suspected carcinogen in animals, protests have been registered against acesulfame-K's initial approval in the U.S. Overseas, where there is a greater selection of available sweeteners, it has been successfully used in mixtures. Nonnutritive sweeteners frequently show a synergistic effect when used together, resulting in a sweetness level several times greater than the individual components. This allows for decreasing use levels, offers cost savings, and gives formulators a means to get desirable taste profiles under various conditions, minimizing the negative features of one sweetener while maximizing the positive aspects of another.

Also awaiting FDA approval are alitame and sucralose. Maybe closest to approval, according to Nabors of the

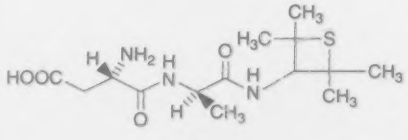
Variety of sweeteners used in low-calorie food formulations



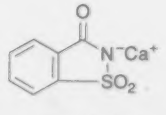
Sucralose



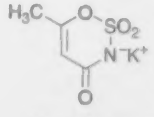
Cyclamate



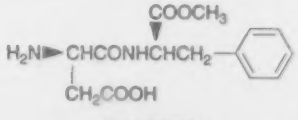
Alitame



Saccharin



Acesulfame-K



Aspartame

Use of flavors changes to meet demands of low-fat, low-calorie foods

The market for flavors has been affected greatly by the move toward low-fat, low-calorie, and convenience foods. Although consumers say they desire foods that are "healthier," an overriding demand is that foods taste as good as, if not identical to the real thing. For these new food formulations, flavor producers are using new technologies, including biotechnology, to come up with flavors. These new flavors are going into a wide range of markets including dairy, meats, seafood, and baked goods, and into many products that never before required their use.

Flavorings often are needed because reducing fat, sugar, salt, or calories leads to a decrease in palatability that is not supplied by replacement materials. In reduced-fat products, the challenge is to overcome not only the loss of flavor once provided by fat itself, but also the loss of functionality: Fat carries fat-soluble flavors and vitamins and, because of the "feel" it has in the mouth and its ability to linger there, it contributes to how flavors are perceived. Many food industry observers say the fatlike flavors and effects needed have not yet been achieved.

Fat also contributes flavors produced through cooking and/or frying. When foods are browned during cooking—known as the Maillard reaction—proteins, amino acids, fats, and carbohydrates react in the presence of heat. In order to produce these flavors in reduced-fat products, cooking processes or enzymatic reactions must be mimicked. Convenience products, such as those for the microwave, require flavors that develop quickly and are strong and stable enough to survive freezing and heating cycles.

Considerable changes are needed to formulate flavors for use in no-fat products, says Tracey Glancy, director of marketing and new business development at Imcera's and Hercules' 50-50 flavor joint venture. In February, the Fries & Fries flavor business of Imcera's Mallinckrodt Specialty Chemicals was combined with the PFW and citrus specialties flavor businesses of Hercules to form a yet-unnamed Cincinnati-based company. "We [also] have found that the same flavor doesn't necessarily behave the same way if the fat replacement system changes." To get satisfactory food formulations, flavor houses are working closely with customers, often on a product-by-product basis.

Some in the food industry put off by the added costs from flavors in new product formulations. An example Glancy gives is a lean hamburger for which flavors are needed when the fat is removed. "To people who have never used flavors, they look very expensive," she says. "Flavors sell in dollars per pound, but are used at very low levels. It is possible to use flavors in products like meats without making the price [of the product] prohibitive."

Overall, the market for flavors is anticipated to grow 6.2% annually, making it among the fastest growing food additive markets. It is estimated to grow from sales of $675 million in 1991 to $911 million by 1996, according to the Pathfinder report put out by the Business Research Group of Technomic Publishing Co. As has been the trend for several years, the demand for natural flavors outweighs that for artificial ones by 3 to 1, even though natural flavors tend to be less intense and less predictable when used in food products.

Calorie Control Council, is sucralose (1,6-dichloro-1,6-dideoxy-β-D-fructofuranosyl-4-chloro-4-deoxy-α-D-galactopyranoside), the only nonnutritive sweetener based on sugar. As a selectively chlorinated form of sucrose with a glycosidic linkage more resistant to acid or enzymatic hydrolysis, it is not metabolized. It has 400 to 800 times the sweetness of sucrose, has a high solubility, and is very stable to heat. It has been described as having a "high quality" of sweetness.

Jointly developed by Tate & Lyle and McNeil Specialty Products, a subsidiary of Johnson & Johnson, sucralose will be marketed in the U.S. by McNeil. It has been under review at FDA since 1987. In September 1991, Canada granted marketing approval in 13 food categories to an affiliate of Tate & Lyle for its Splenda sucralose product.

Alitame (L-α-aspartyl-*N*-(2,2,4,4-tetramethyl-3-thietanyl)-D-alaninamide) is another amino-acid-based sweetener, like aspartame, but includes a novel amine. Although it also is metabolized, at 2000 times the sweetness of sucrose, it is essentially noncaloric in use. Pfizer says alitame has a "sweet, clean taste." However, under acidic conditions at high temperature, it may have an "off" flavor. The company's petition for FDA approval has been pending since 1986, but review has been delayed by the need to repeat a study, says Nabors. Alitame's approval would round out Pfizer's position in the light food area.

Other heat-stable sweeteners are expected to displace saccharin (the calcium or sodium salt of 1,2-benzisothiazol-3(2*H*)-one 1,1-dioxide), which has been on the market for nearly a century and has survived a proposed FDA ban, overturned repeatedly by Congressional moratoria. Manufactured by PMC of Cincinnati, saccharin has 300 times the sweetness of sucrose. Despite a bitter aftertaste and the health controversy that has surrounded it, saccharin is used in a wide variety of applications.

FDA banned Abbott Laboratories' cyclamate (sodium cyclohexylsulfamate) in 1970, but the company has had a petition for reinstatement pending with the agency for several years. Results of animal studies that led to concerns of cancer and to the ban on cyclamates have been brought into question. Nabors is optimistic about its chances both for reapproval in the near future and about its reentering the market after having been banned. One disadvantage of cyclamate relative to other sweeteners is that its sweetness is only 30 times that of sucrose.

Other high-intensity sweeteners are in earlier stages of development, having not yet made it before FDA, or with limited approvals overseas. These include dihydrochalcones derived from bioflavonoids of citrus fruits; stevioside extracted from a South American plant; glycyrrhizin extracted from licorice root (used as a flavor enhancer in the U.S.); and thaumatin, a mixture of proteins taken from a West African fruit.

Left-handed sugars also are under development. These are not expected to be metabolized, but are expected to perform the same physically—providing the bulk, texture, taste, and cooking properties of normal sugars. □